

ACTIVITY REPORT

March 2001



**Natural
Gas &
Oil
Technology
Partnership**

bringing department of energy national laboratories capabilities to the petroleum industry

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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November
Oil and Gas Recovery Technology
Drilling, Completion, and Stimulation Technology
Diagnostic and Imaging Technology

February, April, June, August, October, December
Upstream Environmental Technology
Downstream Environmental Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: <http://www.sandia.gov/ngotp/>

Oil and Gas Recovery Technology

Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Highlight:

- Core from five wells selected for laboratory testing.

By injecting diluted reservoir brine in laboratory corefloods, waterflood oil recovery can be significantly increased under certain conditions.

The University of Wyoming (UW) has investigated the importance of clay particles in the recovery process. In recent work, clay particles were reintroduced into fired and acidized Berea sandstone core plugs, and waterflood experiments with various crude oil and brines were conducted. It was shown that the presence of potentially mobile fine particles was essential to increase oil recovery by means of injection brine dilution. When using cores that had clay particles reintroduced, the effect of brine dilution on oil recovery was smaller and less consistent than results obtained using unfired sandstone. While these results are not discouraging, they do not provide evidence that reintroduction of clay into a core will restore sensitivity of crude oil recovery to injection brine salinity.

INEEL and UW researchers are conducting a series of experiments to elucidate the mechanisms of increased recovery for Minnelusa crude oil (an asphaltic oil) and Minnelusa brine and Berea sandstone. These experiments will be followed by similar experiments using crude oil from the Monument Butte Field in the Uinta Basin of Utah, which contains a waxy crude oil. Following successful conclusion of these experiments, field cores will be used in place of Berea sandstone to further elucidate the impact of rock characteristics on the oil recovery from dilute brine injection.

A series of eight Berea sandstone corefloods were conducted using simulated Minnelusa reservoir brine and Minnelusa crude oil. Minnelusa reservoir brine was used as the initial formation brine, and all cores were aged at initial conditions for 14 days at 55°C and then waterflooded at room temperature. Four of the cores were flooded with a 100-fold dilution of formation brine, and the other four were flooded with full-strength formation brine. No increase in oil recovery was seen when the diluted brine was used as the injection fluid relative to the reservoir brine for these mild aging conditions, which may not have shifted the wettability enough to create the conditions required for increased recovery. A second set of experiments is under way where the aging temperature is 75°C, and the flooding is being conducted at 75°C as well. Results for one test with diluted brine showed more than a 20% increase in recovery. A second test showed a lower recovery, but the core material was of a lower permeability and higher initial water saturation, which may have influenced the results. Additional tests are planned.

The UW is conducting experiments on the same Minnelusa system and evaluating the impact of varying levels of initial water saturation on the results. The combined results of INEEL and UW experimental results are anticipated to increase the understanding of the mechanisms controlling the process.

Development of a New-Generation Petroleum Reservoir Simulator

(BP, Chevron,

Conoco, Cray Research, IBM, Landmark Graphics, Schlumberger-GeoQuest, Scientific Software-Intercomp, Texaco, Unocal, UT-Austin, and ANL)

Highlight:

- Significant achievements summarized as project funding ends.

Now at the end of its funding, the project's research and development paid off in significant accomplishments. The IPARS (Integrated Parallel Accurate Reservoir Simulator) framework and some of the reservoir models have been released to affiliates.

Development of a New-Generation Petroleum Reservoir Simulator

(continued)

The project was initiated under the auspices of the Advanced Computational Technology Initiative and funded by the Office of Science. This project also has been highly leveraged throughout its duration by related work at both ANL and the University of Texas. Significant project accomplishments are summarized below.

- Development of a modular structure framework enabling new physics to be studied with only incremental coding. The IPARS framework provides all memory management, well management, message passing, table lookup, input/output, etc., so that the user need only write code for the relevant physics. The framework is designed for portability, and researchers have run a variety of physical models on PCs (Windows and Linux), workstations, and several parallel platforms with no special adaptation of the code between machines. One of the key features in the design of the IPARS framework is the capability to select application components at compile time and at run time, greatly facilitating the integration of other codes, as well as new enabling technologies as they become available. The design paid off handsomely in the last year when the IPARS framework was successfully coupled to several different external software packages. For example, IPARS is now one of the applications available at the NetSolve project. Developed at the University of Tennessee, NetSolve allows remote launching of applications on participating machines anywhere in the world. The user can conduct all the usual business of reservoir simulation—edit IPARS input files, submit the job, monitor its progress, view the result—entirely through a web-browser interface. IPARS was also integrated with the DISCOVER collaborative environment developed at Rutgers University, which enables multiple users to monitor simulation results simultaneously and in real time, as well as to steer the simulation interactively. Successful live demonstrations of the NetSolve/DISCOVER/IPARS system were given at the ACCESS center in Washington DC, the Industrial Affiliates Meeting of the Center for Subsurface Modeling at UT, and at SuperComputing 2000 in Dallas.
- Development of a fully implicit equation-of-state (EOS) 3D compositional model, general-purpose parallel adaptive simulator.
- Incorporation of the linear solvers from ANL's PETSc package into the simulator. (Simulator performance and scalability largely depend on solver performance.)
- The same code can run on a full range of systems from a single PC or workstation, clusters of PCs or workstations, to the highest-end, highest-performance systems available. Simulations are limited only by the size of the problem to be addressed and the system available—not by fundamental technology constraints.
- Excellent simulator performance and scalability on realistic problems demonstrated on clusters of PCs and proprietary parallel computers. The former, especially, puts simulation within economic reach of the smaller independent producers. For example, in a series of sample problem runs, the time to solution for a 16-processor PC cluster was roughly twice that of a 16-processor IBM SP system (i.e., 1 hour versus 30 minutes), while the cost of a cluster is roughly one-tenth that of an SP system (approximately \$40K versus \$400K). Comparisons on PC clusters using several types of communication hardware (Ethernet, Myrinet, and Giganet) have been made. PC cluster performance typically has been at 70% to 100% of that seen on the proprietary platforms. Test problems on clusters using the EOS compositional model included realistic problems with up to 500,000 gridblocks, with up to 13 wells, with up to six components, and with both layered- and stochastic-permeability reservoir descriptions. The largest problem run to date stands at four million gridblocks and 32 million unknowns in approximately 23 minutes on a 128-processor IBM SP.

**Development of a
New-Generation Petroleum
Reservoir Simulator***(continued)*

- Development of multiblock, multimodel domain decomposition approaches for non-matching grids. In the past, reservoir simulators were developed with a focus on a particular physical process, e.g., waterflooding or miscible-gas flooding. As field development strategies become more complex, several recovery processes often occur simultaneously within the same reservoir. Through the development of the multiblock paradigm, project researchers broke the restraint of traditional “one-process-at-a-time” simulators that cannot adequately couple the different domains in such fields. The IPARS framework permits rigorous, physically representative coupling of different flow models in different parts of the domain. Recently, participants extended the treatment of the interface between blocks so that different formulations or physical models can exist on each side of the interface in the same run. This multiblock/multiphysics approach—a capability unique to IPARS—allows coupling of non-matching grids (in particular, it allows local mesh refinement). There are two paradigms for multiblock under IPARS: (1) the mortar and (2) dual approaches. While their functionality is similar, the convergence rates and efficiency may differ. Both dual and mortar approaches allow coupling of different physical models. On parallel platforms, some of the critical issues in efficiency were identified, including load balancing. Specifically, the cost ratio between the individual models and the size of the model subdomains were considered as the main factors determining efficiency. Also, new interface preconditioners appropriate for multiphysics were developed. The efficiency of the multiphysics/multinumerics approach was demonstrated for cases with two physical models, one of which was substantially slower than the other. Tested examples include a single-phase model with a two-phase model, a two-phase IMPES (implicit pressure, explicit saturation/concentration) model with a two-phase implicit model, and a two-phase implicit model with a black oil model. If the faster model occupied a large subdomain compared to the slower, or if the slower model was assigned a higher number of processors, the multiphysics approach ran faster by up to 30% than a single model with no-domain decomposition. The efficiency increased by a factor of seven times if multiphysics was also combined with local grid refinement.
- Implementation of a restart capability for multimodel cases and multiblock geometries. This capability expands the flexibility of the framework because it allows for a form of adaptivity. In particular, one can run multiblock simulations in which the mortar spaces (dimensions and type) can vary between time steps, which can provide significant improvement in efficiency, depending on the location of saturation fronts relative to the block boundaries.
- Development of multiple physical models. Considerable effort has been spent on hardening the code and improving its efficiency and robustness. In particular, these improvements include validation of models, progress in multiblock/multiphysics solvers and preconditioners, multigrid and other preconditioners, and well implementation. Several IPARS physical models have been validated against existing data, analytical results like Buckley-Leverett, or other codes (Eclipse). Results from the environmental air-water model agree with some laboratory experiments (by J. Touma and M. Vauclin). In another direction, a different formulation of the black oil model was tested in which the chosen set of primary variables (P_o , N_o , N_g) differs from the one used so far (P_w , N_o , N_g). The results of this new model present a unique opportunity to test the significance of choice of primary unknowns in models operating in the same environment.
- Development of a lightweight visualization option has proven extremely useful for examining details of flow between wells or through extremely heterogeneous regions of the reservoir.

Development of a New-Generation Petroleum Reservoir Simulator

(continued)

- Development of a portable, scalable interactive visualization tool. The visualization of large-scale simulations presents several problems related to (1) size of the problem, (2) irregular grids, and (3) parallel decomposition of the grid cells among processors. A typical large-scale problem has on the order of a million or more cells. For a multiphase flow model (e.g., black oil model) one may want to visualize several variables associated with the flow, and at the very least, all primary variables (three in this case). The size of the visualization dataset may easily reach 1GB or more. Unfortunately, commercial visualization tools, quite suitable for small-sized problems, are inadequate for such large datasets. Collaboration with ANL's Futures Laboratory as well as with the University of Minnesota has allowed use of high-end visualization tools developed by these partners to analyze and interpret IPARS results. These software tools post-process the output datasets and create "movies" with which the user, employing a CAVE or Immersadesk display device, can "step inside" the 3D image to explore in detail critical regions near wells and faults. The images can simultaneously convey a range of relevant information. For example, pressure is shown using cutting planes, and saturations are shown using isosurfaces that can be colored by other variable values. In addition, vector velocities and streamlines can be added to the overall picture. The tool is scalable and operates on distributed machines. A desktop workstation can also be used for display, although the small size of the display area limits its usefulness.
- In another direction, a project on history matching and geostatistical simulations with IPARS using the software package Active Data Repository has been initiated and will be continued through leveraging by other resources. Another software package, Metachaos, is being used to couple IPARS with the surface water code UTBEST for use in environmental applications.
- Multigrid or agglomeration techniques for linear solvers and interpolation and flexible inexact nonlinear solver techniques have been studied, implemented, and applied. It appears that a physics-based multigrid-type approach may lead to faster code than the generally known optimal algebraic-type multigrid solvers. Also, fully implicit wells and horizontal wells development is under way. (Further development will require additional funding.)
- Development of an object-based Fortran 95 toolkit to streamline the use of automatic differentiation based on ANL's ADIFOR tool. The principal design idea of the toolkit is the use of opaque objects to represent important components. These objects have a fixed interface, behind which the implementation details are hidden from the toolkit user, which allows the implementation to be modified or replaced entirely without requiring any changes to the physics code that uses the toolkit. The objects are designed to plug together, but can be used separately, as well. The application developer is free to pick and choose from among the toolkit components. The use of standardized interfaces allows application developers to take advantage of whatever cutting-edge software is available from other sources. Through the use of these interfaces, the toolkit hides from application developers as many of the implementation details of a large-scale parallel simulator as possible. (Further development of this toolkit will require additional funding.)
- Project work yielded 27 journal articles, two book chapters, 24 conference proceedings, 45 presentations, 13 technical reports, and nine related Ph.D. dissertations. Further information can be found on the project's Web site at http://www.pe.utexas.edu/CPGE/new_generation.

Fluid Identification Acoustic Logging Tool

(BP Amoco, CGG, Chevron, Conoco, Landmark Graphics, Mobil, Schlumberger, Shell, Smedvig, Texaco, Unocal, Ward Petroleum, Western Atlas, and LANL)

Refinement of the electronics design for resonance peak frequency tracking were made to enable real-time monitoring of oil/water composition. Preparations were completed for verification of the current measurement circuitry through experiments in the three-phase flowing well simulator. Once verified, the circuitry will be reconfigured for insertion into the tool's electronic subassembly.

**High-Resolution Reservoir Characterization
Using Seismic, Well, and Dynamic Data**

(BP Amoco, Chevron, Exxon, Oxy, Phillips, RC2, Texaco, Western Geophysical, Texas A&M, and LBNL)

Highlight:

- Technology commercialized and used successfully by Saudi Aramco.

The project is in the close-out phase, and no funding was requested for the current year. At the request of the editor, LBNL researchers are writing a review article for an upcoming issue of the *Oil and Gas Journal*. This paper describes the accomplishments of the project collaboration and discusses possible extensions of our methodology.

LBNL has been active in transferring the technology to industry via commercialization. A commercial package called 'RESMATCH' is already available and is being marketed by Reservoir Characterization and Consulting (currently Veritas).

Saudi Aramco has successfully applied the commercial package for conditioning multimillion-cell geologic models to 30 years of production history. This work will be presented at this year's Society of Petroleum Engineers annual meeting. Encouraged by the initial success, Saudi Aramco has entered into a multi-year contract with Texas A&M to support a research associate for further development of the streamline-based inversion approach to account for gravity-dominated flows and rapidly changing field conditions arising from rate changes, infill drilling, pattern conversion, etc.

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, Yates Petroleum, UT-Austin, Texas Tech University, and SNL)

Highlight:

- Gas locking achieved.

Gas locking has been achieved in the instrumented pump at University of Texas-Austin. Measurements made on the gas-locked pump confirm predictions as to the physics governing gas locking and determining when gas locking occurs. As predicted, gas locking is different from gas interference (pumped off well).

A computer model is being developed to analyze data collected with the instrumented pump. The model will be a valuable tool in determining the boundary conditions for wave-equation solutions to sucker rod dynamics.

Stuffing box friction continues to provide surprising features in the measured data.

Formation Logging Tools for Microboreholes

(DeepLook, Texaco, and LANL)

Highlights:

- Comparative measurements of microhole and commercial gamma tools resume.
- Abstract accepted for the American Geophysical Union meeting.

Magnetic shielding stock was procured and fabricated as shrouds for both the commercial and microhole tools. The shielding precluded any anomalous photomultiplier behavior due to residual magnetization present in the various steel casings used in measuring the relative performance of the microhole and commercial gamma tools. An apparent degradation in the performance of the microtool's photomultiplier was noted. The K40 spectral peaks were found to progressively shift downward in energy with the amount of time voltage was applied to both the microhole and commercial tools while they were immersed in potash. After 48 hours, the spectral shift of the commercial tool stabilized at a small value of 10 keV while the microhole tool continued to shift downward with time. We are working with the manufacturer to determine the cause of the drift. Work began in identifying the technical challenges of fabricating and using neutron and gamma-ray absorption logs in microholes.

An abstract for a paper describing progress to date in microhole technology was submitted and accepted for presentation at the Spring Meeting of the American Geophysical Union in Boston:

Albright, J. N. "Microhole technology - Progress in drilling and instrumentation development."

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling

(Mobil, Schlumberger, UT-Austin, and SNL)

Highlight:

- IPARS modification allows flow simulator more accurate prediction capabilities.

Project researchers have observed that the convergence behavior of the flow simulator (IPARS) conjugate gradient solver changes when large porosity changes are passed from JAS3D. Recent modification to the Jacobian and conjugate gradient preconditioner in IPARS now allows the flow simulator to more accurately predict these large changes and to robustly handle porosity and permeability changes arising from large volumetric strains computed in the geomechanical code. This modification makes use of the traditional rock-compressibility term in the flow simulator to obtain a better estimate of the preconditioner for the conjugate gradient solver.

Semiautomatic System for Waterflood Surveillance

(Aera Energy LLC, Atlantis Scientific, Chevron, Electromagnetic Instruments, Integrated Micro Instruments, and LBNL)

Highlight:

- Preparations begun to install an automatic injection surveillance system.

LBNL has developed a control model of water injection from a growing hydrofracture into a layered soft rock reservoir. The reservoir may undergo damage caused by changing rock stress from oil withdrawal and injection of water. Analysis of actual oil-field water injection rates and wellhead pressures leads us to believe that direct hydrologic links between injectors and producers can be established at early stages of waterflood, especially if the injection policy is aggressive.

Based on our model, we propose an optimal controller for transient and transient/steady-state water injection into layered rock. We design the optimal injection pressure that manages the rate of water injection in accordance with the hydrofracture growth and other rock damage factors. We estimate the formation damage and the distribution of the injected water between transient and damaged layers by analyzing the changing injection rates and pressures. The model has been verified against field data. It produced a remarkable agreement between calculated and observed parameters.

Drilling, Completion, and Stimulation Technology

Evaluation of Concepts and Components for Directional Underbalanced Drilling and Microdrilling

(DeepLook, Fleet Cementers, Maurer Engineering, Mobil, Texaco, U of Tulsa, and LANL)

Project closed out December 2000.

Real-Time Coiled Tubing Inspection System

(Quality Tubing and INEEL)

Highlight:

Fatigue tests and the final report are in progress.

- Hall probe system completed and used to test samples.

Perforation Dynamics in Geological Media

(Columbia Gas Transmission, Halliburton, National Fuel & Gas Supply, Panenergy, and LLNL)

Highlight:

- Improved procedure implemented to deduce permeability from analysis of x-ray CT measurements of front position.

Improvements have been made in the analysis procedure by which permeability was deduced from experimental x-ray computed tomography (CT) data. The original method—based on 1D radial slices—excludes consideration of axial flow components and does not account for fluid mixing or non-uniform porosity. The new method employs a fully 3D simulator to predict the position of the viscous front. The predicted front position histories at each scan position are compared to the experimental observations, and an error function is generated. The permeability map is then adjusted iteratively to minimize the error. Because large numbers of forward simulations are required with this technique, an artificial neural network is being developed to speed up the procedure.

Drill Cuttings Injection Field Experiment

(BP Amoco, Chevron, Exxon, Gas Research Institute (GRI), Halliburton Energy Services, Hughes Christensen, MSD, Pinnacle Technologies, Schlumberger, Shell, and SNL)

Project is in close-out phase; reporting and technology transfer are under way

Seismic Stimulation for Enhanced Production of Oil Reservoirs

(AERA Energy, Applied Seismic Research, Chevron, Conoco, Fluidic Technologies, Halliburton, Marathon, OGC Management, PerfClean, Phillips, Piezo Sona-Tool, Texaco, UC-Berkeley, LANL, and LBNL)

Highlights:

- Diffusion and Laplace equations for stimulated fluid flow solved.
- Final project meeting announced.
- Expanded abstract submitted to SEG annual meeting.

An homogeneous diffusion equation and a Laplace equation, whose dependent variables are linear combinations of fluid pressure and dilatational stress, were previously derived from coupled momentum balance equations for an elastic porous medium containing two immiscible fluids. Under a constant pressure gradient, and with the input of pulsing pressure and constant load on one boundary, the pore pressure distribution for a semi-infinite porous medium containing oil and water can be determined. Thus, the time-variation of the flow rate can be predicted as the function of the frequency of pulsing.

A final general meeting for the project is scheduled for April 25 at LBNL. Project accomplishments, the current state of seismic stimulation research efforts, and proposals for continuing the research will be discussed.

An expanded abstract was prepared and submitted to the Society of Exploration Geophysicists annual meeting to be held in San Antonio, September 2001:

Roberts, P., Kostrov, S., Wooden, W., Majer, E., and Daley, T. "Laboratory and field observations of stress-wave induced changes in oil flow behavior."

In-Well Imaging and Heating: Multiple-Use Well Design (Aera Energy LLC, Chevron, SteamTech Environmental Services, and LLNL)

Report not received.

3D Analysis for Induction Logging in Horizontal Wells (BP Amoco, Chevron, Conoco, Electromagnetic Instruments, Exxon, Halliburton, Mobil, Phillips, Schlumberger-Doll, Shell, Texaco, Unocal, Western Atlas, and SNL)

Highlight:

- 3D anisotropy formalism recast in terms of a matrix-free implementation.

Work continues on several publications in the area of anisotropy effects in induction logs. A short note to *Geophysics* has undergone peer review; changes have been made, and final word on the paper's publication status is pending. A companion paper to the *Geophysics* short note has been accepted for publication in *Petrophysics*; a revised version is nearly complete and should appear in print soon. Another manuscript on the 3D finite-difference formalism, also submitted to *Geophysics*, has undergone peer review; revisions are under way. Two extended abstracts have been submitted for presentation at the 2001 Society of Exploration Geophysicists annual meeting in San Antonio. Work is concluding on an open-distribution SNL report which is a compendium of induction sonde sensitivity analyses for horizontal wells.

In terms of research, the 3D anisotropy code has been ported to FORTRAN 90 to facilitate its portability and simplify its use by the end user. Also on the code development front, the 3D anisotropy formalism has been recast in terms of a matrix-free implementation. This is a significant development in that the matrix-free methodology eliminates the massive storage costs associated with storing the finite-difference coefficient matrix without penalty to the computational throughput. The next stage in the development of the 3D code is to implement a parallel version for use on distributed memory compute clusters, much like the recently developed isotropic code, in which a single logging point is computed on each compute node—thus realizing almost ideal scaling with problem size owing to the minimum of interprocessor communication.

As a second research thrust, work on fast 1D forward modeling and inversion has been proceeding as scheduled. Along with the previously developed work on fast simulation and inversion of inductive sources in 1D anisotropic media, researchers are nearing completion of simulation of the direct current response of a 1D anisotropic medium. Together, these modeling capabilities will provide a complete package for analysis of electrical, induction, and hybrid logging devices. As a testbed, work is under way for the analysis of laterolog data.

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling (Chevron, INEEL, and LBNL)

Highlights:

- Feasibility report completed.
- Savoy Field Research Facility selected for prototype testing.
- Constructed prototype.

Designing began on a new capacitive discharge prototype seismic source. This effort included developing specifications, conceptual drawings, and cost estimates. The FY01 Field Work Proposal was completed and submitted for funding authorization. Project is on hold until funding is received.

Acoustic Telemetry (MWD)

(ABB, Passband Downhole Communications, Electroacoustics Research Laboratory, and SNL)

Highlights:

- Repeater hardware received.
- Field test preparation under way.
- Surface-receiver contract placed.

Three contracts have been placed with Extreme Engineering in Alberta, Canada. Extreme will harden the final assembly of the downhole telemetry transmitter and prepare it for field deployment. Next, they will assist in field tests in both a test well and a commercial well. Finally, they have been contracted to design and construct two surface-receiver prototypes. These devices, which will mount directly to the rotating drill pipe above the rotary table, will sense the acoustic telemetry signal, digitize it, and transmit the information to the computer acquisition system via a radio frequency link.

The project also received all the hardware components for the full-scale repeater model. These components will allow us to assemble a “bread-board” repeater system at the project’s surface facility and begin designing the digital signal processing algorithms—the core of the repeater concept.

Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

Highlights:

- Alternative ceramic borehole sealant formulations based on aluminum phosphates identified.
- First field demonstration planned of Ceramcrete in downhole wellbore water shut-off application.

Testing at Chevron established that Ceramcrete formulation is valid for applications in wells with maximum temperature of 150°F and a pressure of 6150 psi. At this temperature and pressure, the pumping time was found to be three hours, which is considered to be the minimum time needed to pump cement. All attempts to increase this time by adding commercial retardants failed. It was clear that a novel chemically bonded phosphate ceramic system needed to be designed to meet the pumping time requirements above 150°F.

Basic thermodynamic modeling and initial tests conducted at ANL revealed that aluminum phosphate-based cementing formulations may meet these needs. Several tests were conducted in a conventional oven at temperatures ranging between 150°–300°F, and different aluminum oxide and hydroxide-based formulations were identified. Currently, the oxides used in these formulations are being fully characterized before being subjected to consistometer tests at Chevron.

At LANL, preparations are under way for a field demonstration of the Ceramcrete formulation for water shutoff in a downhole application. Plans are to conduct this demonstration in May using the formulation that has already been tested according to American Petroleum Institute standards in Chevron’s laboratory.

Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring

(DeepLook, Phillips, Texaco, and LANL)

San Ysidro Demonstration**Highlights:**

- 600-ft microhole at San Ysidro successfully plugged.
- Planning for a second well commenced.

After the project team’s unsuccessful attempt to complete the well below the lowest aquifers, we were also unsuccessful in using drill rods to wash over and remove the cemented 1-1/4-inch PVC casing. We initially had tried to complete the well with 1-1/4-inch PVC tubing at a 340-ft depth between the two flowing aquifers. Shortly after the cement was pumped around the bottom of the casing, however, the pump pressure increased rapidly, indicating a flash set or plugged annulus. The cement could not be circulated to the surface; therefore, it set inside the casing. The aquifers ceased to flow, so it was assumed that cement had covered the flowing zones. We decided to plug the hole, and spotted three cement plugs in the casing annulus, which successfully plugged the well with a continuous cement column from 340 ft to surface.

Prior to the first cementing at San Ysidro, we had tested cement mixtures with the produced water. These showed no acceleration in set time. Neither our water well cementing consultant nor representatives from the State Engineers

Office can explain the apparent flash setting of the cement based on experience in the area. The best explanation is that low-density fill from the sloughing well was circulated out ahead of the 15 lb/gal cement slurry and bridged off the annulus or clabbered the cement.

Preparation for a second well at San Ysidro has begun. A site that is 130 ft higher than the first well has been selected in order to avoid artesian flow if the same aquifers are penetrated. A modified casing shoe will be used to guide the casing in the hole, and modification of the cementing procedure is being considered.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output, Texaco, and LANL)

Highlight:

- Microhole planned for testing of the MEMS seismic array abandoned.

The second attempt to cement a 1-5/8-in. PVC casing in the San Ysidro microhole, which was planned for testing the MEMS seismic array, failed to produce cement returns to the surface. Nonetheless, isolation of the well from the flowing aquifers was accomplished. (For more details, see Coiled Tubing Deployed Microdrilling - San Ysidro Demonstration, this report.) To comply with regulatory provisions, the well was completely plugged and abandoned. A new site near the abandoned well having the same geology at a higher elevation has been identified for drilling a microhole for testing the array. We are awaiting regulatory approval to commence drilling.

Development of Single-Well Seismic Imaging Technology

(BP Amoco, Chevron, Conoco, Exxon, OYO Geospace, P/GSI, Phillips, Schlumberger, Shell, Texaco, TomoSeis, Unocal, Western Atlas, Stanford, LBNL, SNL, and INEEL)

LBNL and INEEL conducted controlled field tests at the University of California Richmond Field Station to determine the effectiveness of the INEEL tube-wave damper. A series of tests were run using the LBNL single-well system and the INEEL tube-wave damper. Hydrophones and geophones were used in different combinations with different sources. The tests that were conducted in the shallow boreholes (<250 feet) showed approximately 10–15 db of attenuation of the high-frequency sources (500–2000 Hz) but little attenuation of the lower-frequency sources (<500 Hz). These and past tests emphasize that for most single-well applications the best sources will be the higher-frequency ones. The lower-frequency sources will have application where the source-receiver distances are large enough that the data of interest arrive before the tube wave.

Large Downhole Seismic Sensor Array

(Chevron, Conoco, Exxon, OYO Geospace, Shell, Texaco, U of Arkansas, and INEEL)

Highlight:

- Construction of demonstration prototype begun.

The totally passive design was modified and retested in February. The last modifications were made to improve fidelity of the horizontal receipts. Even with the modifications, improvements were not sufficient to make the horizontals read as clearly as the vertical. Further modification may happen as a consequence of future tasks, but this data was included in the final project report, which has been sent for final peer review. (The first submittals of the report may exclude the drawing package.) Additional drawings are being finalized for any requested release.

The totally passive module (Bowspring) is being modified to support another test apparatus. This new concept is part of the new continuation of LDSSA, which will stress “alternative” concepts. The Bowspring will house the amplifiers, support the vertical geophone, and centralize the new sensor package. The new sensor package will demonstrate a different deployment concept, while other efforts will demonstrate another sensor type. The two concepts will merge as one, if both prove promising. Tests of the new deployment concepts should occur in April.

Improved Prestack Kirchhoff Migration for Complex Structures (Conoco, Cray/SGI, Golden Geophysical, Kerr-McGee, Mobil, Shell, and LANL)

No work scheduled.

Locating Geopressured Hydrocarbon Reservoirs in Soft, Clastic Sediments Through Identifying Associated Pressure Seals (Conoco and INEEL)

Highlights:

- Reservoir modeling completed.
- Synthetic modeling completed.

Presentations of the results of the project were given to Conoco, Halliburton, and Schlumberger (WesternGeco and Geoquest). The presentations were well received, and a request was later received from Halliburton to submit a proposal for additional work.

The project has been complete.

Testing Advanced Computational Tools for 3D Seismic Analysis Using the SEG/EAGE Model Dataset (Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco, Edison Chouest Offshore, Exxon, GECO-Prakla, Golden Geophysical, Kerr-McGee, Marathon, Mitchell Energy, Mobil, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco, Union Pacific Resources, Unocal, Western Geophysical, Houston Advanced Research Center/Rice, Stanford, UC-Davis, U of Houston, LANL, LLNL, and ORNL)

Highlights:

- Preparations made to process and image physical model vertical cable data.
- Expanded abstract submitted to SEG annual meeting.

Vertical cable data from eight cables acquired over the SEG/EAGE physical model have been loaded onto a workstation at University of Houston/Allied Geophysical Laboratories. The raw data have been sorted as receiver gathers and averaged to 8ms sample intervals to reduce the volume without sacrificing the quality. Texaco is making necessary modifications to the software package “Seispak” so that it can be installed and run on the AGL computers.

An expanded abstract on this work has been prepared and submitted for presentation at the Society of Exploration Geophysicists annual meeting in San Antonio in September 2001:

Roberts, P., House, L., Huang, L., Wiley, R., and Sekharan, K.K. “3-D imaging of seismic data from a physical model of a salt structure.”

Integrated Reservoir Monitoring Using Seismic and Crosswell Electromagnetics (Chevron, Electromagnetic Instruments, TomoSeis, LBNL, and SNL)

LBNL has developed a 3D reservoir simulation of the Chevron CO₂ flood in the Lost Hills Field. The simulation has been run from pre-production conditions, through initial (primary) production, and waterflood. This simulation covers the years from the 1940s through 1999 when CO₂ injection began. The final simulations of the CO₂ injection will be done in April. Well logs with sonic, electric, porosity, and saturation have been used to develop petrophysical models relating the reservoir parameters to compressional velocity and bulk

electrical resistivity. These relations have been used to convert the reservoir simulation models into geophysical models. Both 3D crosswell seismic and electromagnetic simulations have been done for comparison to field data. The initial field data acquired before CO₂ injection began have been inverted and compared to the modeled data from the reservoir simulations. Based on the data comparisons, updates to the reservoir flow model are under way.

Frequency-Dependent Seismic Attributes of Fluids in Poorly Consolidated Sands

(Baker-Atlas, Chevron, TomoSeis, Vastar, and LBNL)

Work during this period focused primarily on testing and refining LBNL's combined extensional-torsional wave source and receiver transducers used in its bar-wave resonance and propagation tests. During testing of the source transducer over a frequency range up to 10 kHz, project researchers found flat spectral responses below 4 kHz for torsional excitation and below 9 kHz for extensional wave excitation. Above these frequencies, the spectral responses are contaminated by the fundamental resonance modes of the massive steel transducer.

The receiver was modified for torsional measurements by removing the three-component accelerometer used in previous extensional wave tests and replacing it with three individual accelerometers suitably placed to record extensional (axial) and torsional (azimuthal) particle motions. The axial accelerometer was located in the center of the transducer to minimize the potential of recording spurious bending motions. Two accelerometers located equidistantly from the center of the transducer along a common diameter were oriented so that subtraction of their responses provides the azimuthal particle motion. This differencing configuration was found to effectively remove common electrical noise and, more importantly, was essential in removing large-amplitude, spurious bending modes.

Preparations are under way to begin testing on sand packs with the new source and receivers.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, Conoco Fairfield Industries, GX Technology, Marathon, Texaco, Unocal, and SNL)

Highlights:

- Linear expression linking (unknown) model parameters updates to (known) residual seismograms derived.
- Two expanded abstracts submitted to SEG annual meeting.

Theoretical and algorithmic work pertaining to the development of a full-waveform seismic-inversion scheme is ongoing. The general approach entails iteratively updating an initial estimate of the earth model (a 3D isotropic elastic medium) until observed and predicted data agree. A crucial aspect of the method involves calculation of updates to the model parameters (elastic moduli and mass density) on each iteration of the inversion procedure.

Utilizing the first Born approximation and the reciprocity principle, a linear expression linking the (unknown) model parameter updates to the (known) residual seismograms has been derived. This expression—tentatively named a “time-variant sensitivity equation”—characterizes the sensitivity of particle displacement trace data, for a given source-receiver pair, to small perturbations in the model parameters, as a function of recording time. The expression accommodates all the seismic energy sources and receivers in common use, and readily generalizes to multiple-source/multiple-receiver data acquisition geometries.

A preliminary version of the full-waveform seismic-inversion algorithm, based on the time-variant sensitivity equation approach, has been implemented in a parallel computational environment, and testing of the inversion procedure has been initiated. Numerical evaluation of the coefficients in the linear equations, which entails convolving two 3D elastic wavefields, is computationally

demanding. Efficient methods have been developed for performing these time convolutions. The computed coefficients may be stored in a sparse matrix format. Finally, a search for a rapid and robust technique for solving the resulting large and sparse system of linear algebraic equations for the model parameter updates is under way.

An initial test of the inversion algorithm with synthetic data indicates that it recovered the position and magnitude of two point diffractors located within a uniform background medium. Generalization to more complicated 3D models and recording geometries is ongoing.

Two expanded abstracts were prepared for presentations at the Society of Exploration Geophysicists annual meeting to be held in San Antonio in September. These abstracts treat (1) reciprocity conditions for seismic wavefields propagating within linear anelastic media (heterogeneous and/or anisotropic) and (2) 3D elastic parameter inversion utilizing the time-variant sensitivity equation algorithm.

High-Speed 3D Hybrid Elastic Seismic Modeling

(Burlington Resources,
GX Technology, and LBNL)

Project researchers are working on parallel implementation of elastic finite-difference code in collaboration with NERSC supercomputer center. BoxLib Fortran MPI library is being optimized for work with static grids. Optimization of the library is being tested for an acoustical 3D version of the code with 4th order in space and time differential scheme.

Local PC cluster with Mirinet switchboard is under construction. The cluster will be used for parallel code development and testing to ensure portability. Work continues on extension of nonuniform grid boundary value interpolations.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko,
BHP Petroleum, BP Amoco, Burlington Resources, Chevron, Conoco,
Exxon, GECO-Prakla, Marathon, Mobil, Paradigm Geophysical, PGS-Tensor,
Phillips, Shell, Society of Exploration Geophysicists [SEG], Texaco,
Union Pacific Resources, Unocal, Western Geophysical,
Stanford, U of Houston, LANL, and LLNL)

Highlight:

- Expanded abstract submitted to SEG annual meeting.

Work continued on the theory and verification tests for preserving reflection amplitudes in wave-equation migration. In particular, a general theory was developed to derive the correct weights to be applied during the imaging step of downward-continuation migration. The application of these weights assure the preservation of reflection amplitudes in the migrated Angle Domain Common Image Gathers (ADCIG).

An expanded abstract about this work has been prepared and submitted for presentation at the Society of Exploration Geophysicists annual meeting in San Antonio in September 2001:

Sava, P., Biondi, B., and Fomel, S. "Amplitude-preserved common image gathers by wave-equation migration."

The Partnership Office

Projects Recommendations

DOE has approved the Partnership recommendations, which are based on the industry review panels, for new and continuing projects. These projects will start in the later part of spring as the laboratories receive their FY01 funding. Ten new projects will start in the upstream technology areas. Future editions of this report will highlight these projects. The Partnership thanks the reviewers, the DOE offices, and the principal investigators for their efforts in making this a successful review cycle.

Partnership Representative Changes

Changes have occurred within the roster of Partnership representatives. Earl Whitney, of LANL, who has served as the Partnership co-chair for the last three years, is leaving the Partnership to take on more responsibilities at LANL. Jim Albright, of LANL, will assume Earl's role of lab representative and Partnership co-chair. Also, Bernie Saffell has returned as the PNNL representative.